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NOLTR 62-112

THE DESIGN AND TESTING OF THE NAVAL ORDNANCE LABORATORY'S 2-IN. TWO-STAGE GUN

29 JUNE 1962

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

NOLTR 62-112

Ballistics Research Report 71

THE DESIGN AND TESTING OF THE NAVAL ORDNANCE LABORATORY'S 2-IN. TWO-STAGE GUN

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ABSTRACT: A 2 in. two-stage gun has been successful in launching complex models in the Naval Ordnance Laboratory's 1,000-ft. Hyperballistics Range No. 4 at velocities in excess of 15,000 fps. The design of the 2-inch gun and the results of the first 44 shots are reviewed.

PUBLISHED SEPTEMBER 1962

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

This report presents the successful results of the application of extensive theoretical interior ballistics research to the design of a hypervelocity gun. The purpose of this research was to obtain high-speed aerodynamic data by launching complex missile models in the Naval Ordnance Laboratory's 1,000-ft. Hyperballistics Range No. 4. This work was sponsored by the Re-entry Body section of the Special Projects Office, Bureau of Naval Weapons, under the Applied Research Program in Aeroballistics.

The authors wish to acknowledge the theoretical interior ballistic research of Dr. A. E. Seigel and Mr. D. F. Gates as being the basis for the design of this gun. Acknowledgement is also extended to Mr. E. O. Stengard, formerly of the Naval Weapons Plant, for coordinating the gun design and manufacture.

W. D. COLEMAN
Captain, USN
Commander

A. E. Seigel
A. E. SEIGEL
By direction

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INTRODUCTION

A two-stage, light-gas gun was desired for launching complex models in the Naval Ordnance Laboratory's 1,000-ft. Hyperballistics Range No. 4 at velocities in excess of 12,000 fps. The gun was designed to minimize modifications to the existing gun mount and to the 1,000-ft. range. Space limitations, along with interior and exterior ballistic requirements, resulted in the selection of a 2-inch bore diameter. The installation of the 2-inch gun in the 1,000-ft. range is shown in figure 1.

THE DESIGN OF THE GUN

The 2-inch gun and mount are illustrated in figure 2. Calculated strength values of the 2-inch gun are shown in figure 3. The primary chamber is closed at the rear by a steel cup containing expanding lips on the forward end of the cup as shown in figure 4. The screw box liner, breech plug, and breech plug operating mechanism are standard 12-inch naval gun parts. Primers are attached to a steel rod which is bolted to the breech cup. The bag of gunpowder is placed around the primer rod. The primer ignition wire, piston-type strain-gage connection, and gas-fill lines are brought out through the sealing cup and then through the center of the breech plug.

Illustrated in figure 5 are the piston, the obturating ring for the front end of the primary chamber, the diaphragm, and the diaphragm transition piece. The final version of the piston is a 24-inch-long, low-density polyethylene cylinder with a phenolic sealing plug at the rear.

For the heavy piston firings, a 4° included angle piston buffer was inserted into the high-pressure section of the pump tube as shown in figure 6.

SHAKEDOWN TESTS OF THE GUN AT THE NAVAL WEAPONS LABORATORY, DAHLGREN, VIRGINIA

Initial firings of the 2-inch gun were made at the Naval Weapons Laboratory, Dahlgren, Virginia for reasons of safety and so that existing programs in the 1,000-ft. range could continue. Instrumentation included pressure gages in both chambers and a high-speed camera to measure velocity. A convenient and efficient test procedure evolved at the Naval Weapons Laboratory. Three ordnancemen, two electronics

technicians, and two photographers required about two hours of preparation to fire the gun. The ordnancemen first loaded the missile and locked the barrel up with the pump tube. Next, the piston and primary chamber diaphragm were installed, and the pump tube with attached barrel was locked up with the rear chamber. While this was being done, the photographers loaded and checked out the high-speed camera. Also, the electronics technicians checked the firing circuit and pressure gage circuits. The area was then cleared of personnel and the assembled breech cup, primer rod, and powder bag were brought out of the magazine and inserted into the rear chamber. The breech was then locked and the gas-fill lines were connected. About 15 minutes were required to load gas into both chambers. A sequence timer fired the gun after first starting the camera.

After the shot, powder gas trapped in both chambers by the piston, which was swedged into the piston buffer, was vented. The gun loading procedure was essentially reversed after the shot. At the Naval Weapons Laboratory, the piston was removed with jacks which required from one to three hours. The condensed powder combustion products were removed as soon as possible to prevent rusting. Within three hours after the shot, the film was ready for viewing. A black background, with white vertical lines spaced at one-foot intervals, was placed parallel to the flight path. The projectile velocity could be computed since the film framing speed was known.

Computations were made by the analysis group utilizing the IBM 7090 computer to predict the performance of the 2-in. two-stage gun. This was done using a hydrodynamics computer code based on the Lagrangian scheme. The code solves numerically the problem of one-dimensional flow through ducts of varying cross section including the automatic treatment of multiple shocks. A more detailed report on the method of calculation will be published separately*.

Many calculations were made varying each of the effective parameters of the system, these being the back chamber conditions, the piston weight, the pump tube conditions, the projectile weight and the projectile release pressure. In choosing the initial loading conditions for the shots on the basis of the calculations, two things were kept in mind: the tapered section of the gun could only withstand 125,000 psi and the pressure on the base of the model must not exceed about 35,000 psi.

* NOLTR 62-87, "Computer Analysis of Two-Stage Hypervelocity Launchers" (in preparation)

Tables 1, 2, and 3 list the results of the computer calculations for a 240 gram, 120 gram, and 60 gram projectile, respectively. It is seen from these tables that a heavy piston produces lower model acceleration than the light piston. Figure 7 is a typical distance time plot as obtained from the computer showing the trajectories of shocks between the piston and projectile, the piston trajectory, and the projectile trajectory. Figure 8 is a plot of pressure behind the model as a function of distance along the barrel. Figure 9 is a velocity distance plot of the projectile and shows clearly the impingements of the shocks on the back of the model.

Ten shots were made using the light-piston shock-compressed driver-gas method. The piston was a 0.6-caliber-long polyethylene cylinder. The primary chamber pressure was varied from 17,000 psi to 25,000 psi, obtained by burning gunpowder in the presence of helium. The pump tube was loaded with helium at pressures from 1,500 psi down to 750 psi. Gun functioning and proofing were the main objectives of the first 10 shots since only a 48-caliber-long barrel was available.

Before the 11th shot, a 240-caliber-long barrel was installed. On the first shot with a heavy piston, several inches of the piston buffer were torn off so it was shortened by machining a short 20° angle on the leading edge of the piston buffer as shown in figure 5.

Fifteen heavy piston shots were made. The piston weight was varied from 3,000 grams to 9,000 grams. Primary chamber pressures ranged from 14,000 psi to 25,000 psi. Pump tube loading pressures varied from 300 psi to 1,500 psi of hydrogen. Results of the firings at the Naval Weapons Laboratory are listed in table 4. The over-all performance of the 2-inch gun during the heavy piston shots was satisfactory so test firings at the Naval Weapons Laboratory were concluded after a total of 25 shots.

RESULTS OF FIRINGS AT THE NAVAL ORDNANCE LABORATORY

An urgent, high-velocity program for Project Polaris was awaiting the 2-in. two-stage gun, so installation in the Naval Ordnance Laboratory's 1,000-ft. Hyperballistics Range No. 4 was accomplished in a minimum of time. One test shot was fired and then a series of 19 program shots followed as shown in table 5. Two of the 19 program shots were unsuccessful due to improper model design and the two highest velocity attempts failed. In 15 of the 19 shots, models were launched

successfully up to 15,200 fps. A large percentage of the 19 shadowgraph stations installed in the 1,000-ft. Hyperballistics Range No. 4 operated properly. Aerodynamic coefficients were obtained at Mach numbers 10, 12, and 14. A typical shadowgraph is shown in figure 10. The sabot and model used for the 19 program shots are illustrated in figure 11. The tapered skirt on the sabot serves as a gas seal and as a diaphragm with a release pressure of 5,000 psi. Computations had dictated the unexpectedly high pump tube loading pressure of 1,500 psi. For a heavy missile weight of 250 grams, lower initial pressure causes excessively high accelerations and a rapid loss of driving pressure in the last half of the barrel. The piston was loosened with hydraulic pressure and then driven back out of the pump tube by high-pressure gas. Piston removal can be accomplished in 30 minutes.

CONCLUSIONS

The computer was invaluable as an aid in selecting initial loading conditions to minimize projectile acceleration for a required velocity. Calculations confirmed the fact that a low release pressure for a heavy projectile reduced peak acceleration with little loss in velocity. As can be seen from figure 7, at high initial pump tube pressures, the piston enters the tapered piston buffer too late in the interior ballistic process for the swedging action of the piston to increase the missile velocity.

The 2-inch gun was designed early in 1959. Firing results indicate that the primary chamber is stronger than necessary. Bore erosion is low due to the use of hydrogen at high loading pressures as the driver gas, therefore a spare set of barrels is being made of autofrettaged monobloc construction.

The 2-in. two-stage gun operated with a minimum of mechanical trouble at the Naval Ordnance Laboratory. With improved operations, a firing rate of one completely instrumented program shot per day in the 1,000-ft. Hyperballistics Range No. 4 has been attained.

Back Chamber Pressure (psi)	Pump Tube Pressure (psi H_2)	Piston Weight (gm)	Projectile Release Pressure (psi)	Pressure Felt By Projectile (psi)	Maximum Pressure In Taper (psi)	Velocity 240 Calibers (ft/sec)
20,000	750	5,540	5,000	82,000	125,000	18,200
20,000	500	5,540	5,000	175,000	195,000	18,730*
20,000	750	1,000	5,000	116,900	118,600	14,600
20,000	750	2,700	5,000	91,350	121,200	17,400*
20,000	750	5,540	5,000	82,000	125,000	18,200
20,000	750	9,000	5,000	91,840	123,650	18,500
20,000	1,000	1,000	5,000	111,900	122,900	13,900
20,000	1,000	5,000	5,000	63,000	107,300	17,350
20,000	1,000	9,000	5,000	64,600	112,300	17,600
20,000	1,500	1,000	5,000	61,500	82,600	12,650
20,000	1,500	5,000	5,000	59,450	78,900	15,200
20,000	1,500	9,000	5,000	29,800	81,400	15,000
30,000	1,500	9,000	5,000	69,300	155,700	19,200
30,000	2,000	9,000	5,000	52,000	129,200	17,200
30,000	1,500	18,000	10,000	53,700	128,000	18,500
30,000	2,000	[illegible]	10,000	42,700	112,500	17,100
30,000	2,000	18,000	5,000	32,000	115,350	14,900
40,000	2,000	[illegible]	5,000	107,500	136,700	17,400
40,000	1,500	[illegible]	5,000	114,000	246,500	23,650
40,000	2,500	[illegible]	5,000	76,400	173,600	18,700

* (200 Cal.)
Initial pump tube temperature 300°K

TABLE 1

COMPUTER PERFORMANCE CALCULATIONS FOR 240 GRAM PROJECTILE

Back Chamber Pressure (psi)	Pump Tube Pressure (psi H_2)	Piston Weight (gm)	Projectile Release Pressure (psi)	Pressure Felt By Projectile (psi)	Maximum Pressure In Taper (psi)	Velocity 240 Calibers (ft/sec)
20,000	100	2,000	5,000	178,000	213,000	22,800
20,000	200	9,000	5,000	63,000	125,100	20,000
20,000	300	9,000	5,000	57,300	101,200	20,600
20,000	500	2,000	5,000	87,000	121,700	22,300
20,000	500	5,000	5,000	68,000	126,300	22,000
20,000	500	9,000	5,000	56,400	121,600	20,600
20,000	750	2,000	5,000	54,250	98,200	20,400
20,000	500	18,000	5,000	21,750	64,300	17,800
30,000	500	18,000	5,000	41,600	105,800	20,700
20,000	1,000	18,000	5,000	15,600	80,600	17,100
20,000	1,000	18,000	20,000	41,800	87,400	19,300
20,000	1,000	1,000	5,000	42,000	67,900	17,500
20,000	1,000	5,000	5,000	37,700	106,700	19,900
20,000	1,000	9,000	5,000	23,000	102,500	19,500
20,000	1,500	18,000	5,000	9,300	68,000	12,600

Initial pump tube temperature 300°K

TABLE 2

COMPUTER PERFORMANCE CALCULATIONS FOR 120 GRAM PROJECTILE

Back Chamber Pressure (psi)	Pump Tube Pressure (psi H_2)	Piston Weight (gm)	Projectile Release Pressure (psi)	Pressure Felt By Projectile (psi)	Maximum Pressure In Taper (psi)	Velocity 240 Calibers (ft/sec)
20,000	100	500	5,000	49,000	72,000	25,600
20,000	100	1,000	5,000	69,600	83,000	25,700
20,000	100	9,000	20,000	90,000	122,000	23,200
20,000	300	500	5,000	76,000	101,200	25,300
20,000	300	1,000	5,000	117,700	117,700	27,000
20,000	300	9,000	5,000	35,670	95,300	24,400
20,000	500	9,000	5,000	35,200	117,700	25,200
20,000	1,000	9,000	5,000	13,600	104,000	19,700
20,000	1,000	9,000	20,000	28,700	98,300	20,900
20,000	1,500	9,000	5,000	29,000	161,700	20,100
[illegible]	1,500	9,000	5,000	8,700	82,600	12,600

Initial pump tube temperature 300° K

TABLE 3

COMPUTER PERFORMANCE CALCULATIONS FOR 60 GRAM PROJECTILE

SHOT NO.	MISSILE WEIGHT (grams)	MISSILE TYPE	PRIMARY CHAMBER PEAK PRESSURE (P.S.I.)	PUMP TUBE LOADING PRESSURE (P.S.I.)	PISTON WEIGHT (grams)	MUZZLE VELOCITY (FT./SEC.)	REMARKS
1	117	Nylon Cyl.	17,000	1,500 He	525	---	Missile broke up
2	125	" "	21,000	1,200 He	525	---	" " "
3	125	" "	---	900 He	900	---	" " "
4	130	Lexan Cyl.	23,000	900 He	900	---	Chronograph failed
5	130	" "	---	900 He	900	6,500	
6	130	" "	---	750 He	900	7,000	
7	130	" "	25,000	750 He	900	---	Chronograph failed
8	130	Mg base ≠ Nylon Cyl.	24,000	900 He	900	---	Nylon broke up
9	198	Saboted Mod.	24,000	900 He	900	5,400	
10	193	" "	24,300	900 He	900	---	Camera failed
11	64	Mg. Cyl.	14,300	300 H_2	7090	22,000	H_2 leaked into bore before shot
12	167	Mg. Cyl.	14,600	300 H_2	6950	13,600	
13	236	" "	15,000	300 H_2	5680	13,600	
14	240	" "	18,700	1,000 H_2	5650	12,500	
15	240	" "	21,000	750 H_2	5650	12,500	

SHOT NO	MISSILE WEIGHT (grams)	MISSILE TYPE	PRIMARY CHAMBER PEAK PRESSURE (P.S.I.)	PUMP TUBE LOADING PRESSURE (P.S.I.)	PISTON WEIGHT (grams)	MUZZLE VELOCITY (FT./SEC.)	REMARKS
16	240	Saboted Model	22,000	500 H_2	5670	---	Missile broke up
17	240	Mg Cyl.	18,800	700 H_2	2830	11,100	Piston diameter and seal was changed for shots 17 - 23
18	"	" "	20,000	"	2880	10,500	
19	"	" "	22,000	"	2880	9,500	
20	"	" "	19,500	"	2880	10,800	
21	"	" "	17,800	"	3070	10,900	
22	"	" "	18,800	"	3070	12,400	
23	"	" "	---	"	3070	11,400	
24	252	Saboted Model	---	1,500 H_2	7850	---	Missile broke up
25	230	" "	23,400	1,500 H_2	8660	11,800	Clearance between sabot and bore was reduced over previous shot

Note: The first 10 shots were made in a 48-caliber-long barrel.
A 240-caliber-long barrel was used for shots 11 - 25.
Bore contained air at atmospheric pressure except shot no. 11

TABLE 4
FIRINGS AT THE NAVAL WEAPONS LABORATORY

SHOT NO.	MISSILE WEIGHT (grams)	PRIMARY CHAMBER PEAK PRESSURE (P.S.I.)	RANGE PRESSURE (mm Hg)	MUZZLE VELOCITY (FT./SEC.)
Test	230	17,800	193	11,500
1	253	17,500	98	12,200
2	243	23,000	333	13,700
3	257	---	287	Model Failed
4	254	22,600	82	14,000
5	252	20,300	85	13,000
6	256	16,100	98	12,500
7	256	15,800	99	11,900
8	239	20,500	112	13,600
9	255	15,700	77	11,600
10	252	---	70	14,600
11	252	15,500	88	12,000
12	253	27,200	92	Model Failed
13	254	---	90	11,300
14	225	15,000	91	10,900
15	253	27,500	90	Model Failed
16	253	---	85	11,300
17	258	14,100	84	11,000
18	265	---	85	15,200
19	259	15,200	85	11,400

Note: Pump tube loading pressure was 1,500 psi H_2 for all shots
Piston weight was 8,600 grams
Bore contained air at the range pressure listed for each shot except helium was used on shots 2 and 3

TABLE 5

FIRINGS AT THE NAVAL ORDNANCE LABORATORY

FIG. 1 TWO INCH TWO-STAGE LIGHT GAS GUN IN NAVAL ORDNANCE LABORATORY'S 1,000 FOOT HYPERBALLISTICS RANGE NO. 4

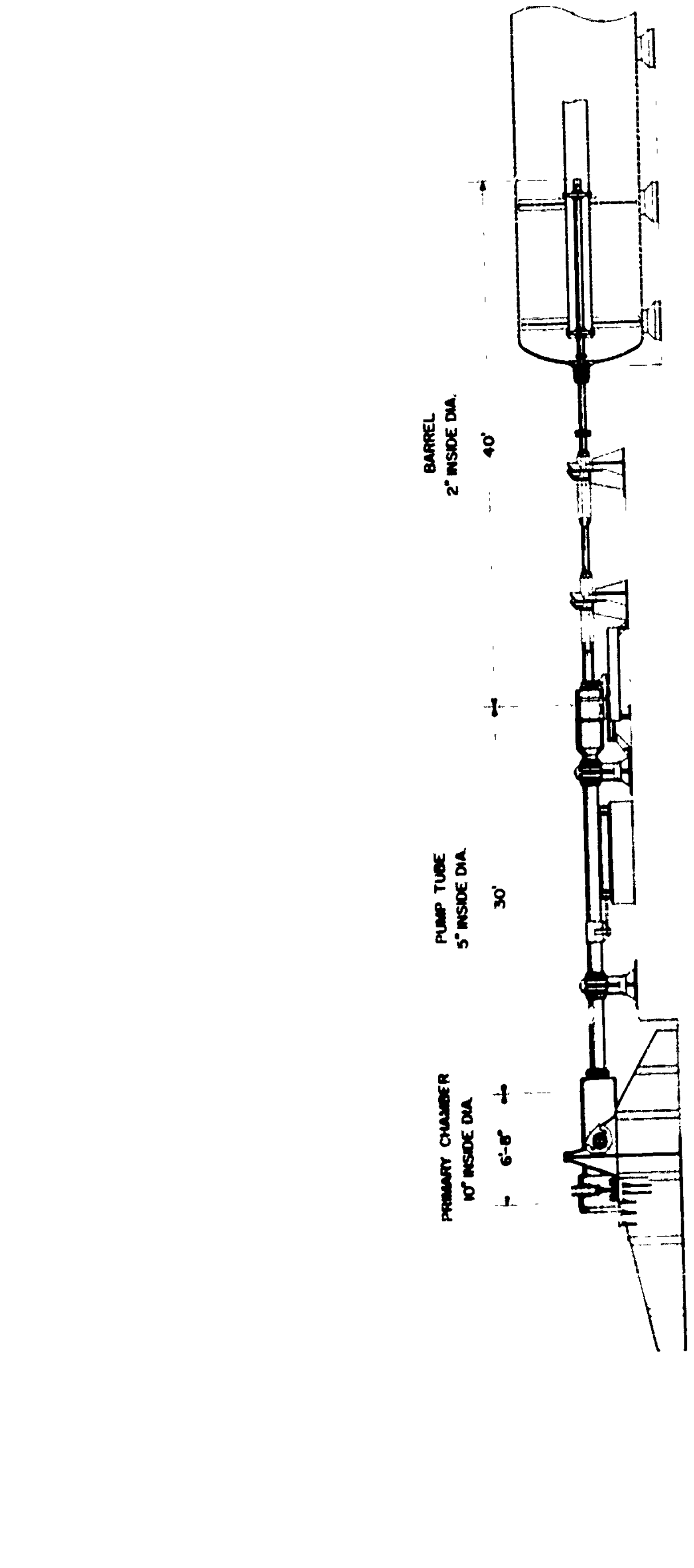

FIG.2 TWO-INCH TWO-STAGE LIGHT GAS GUN

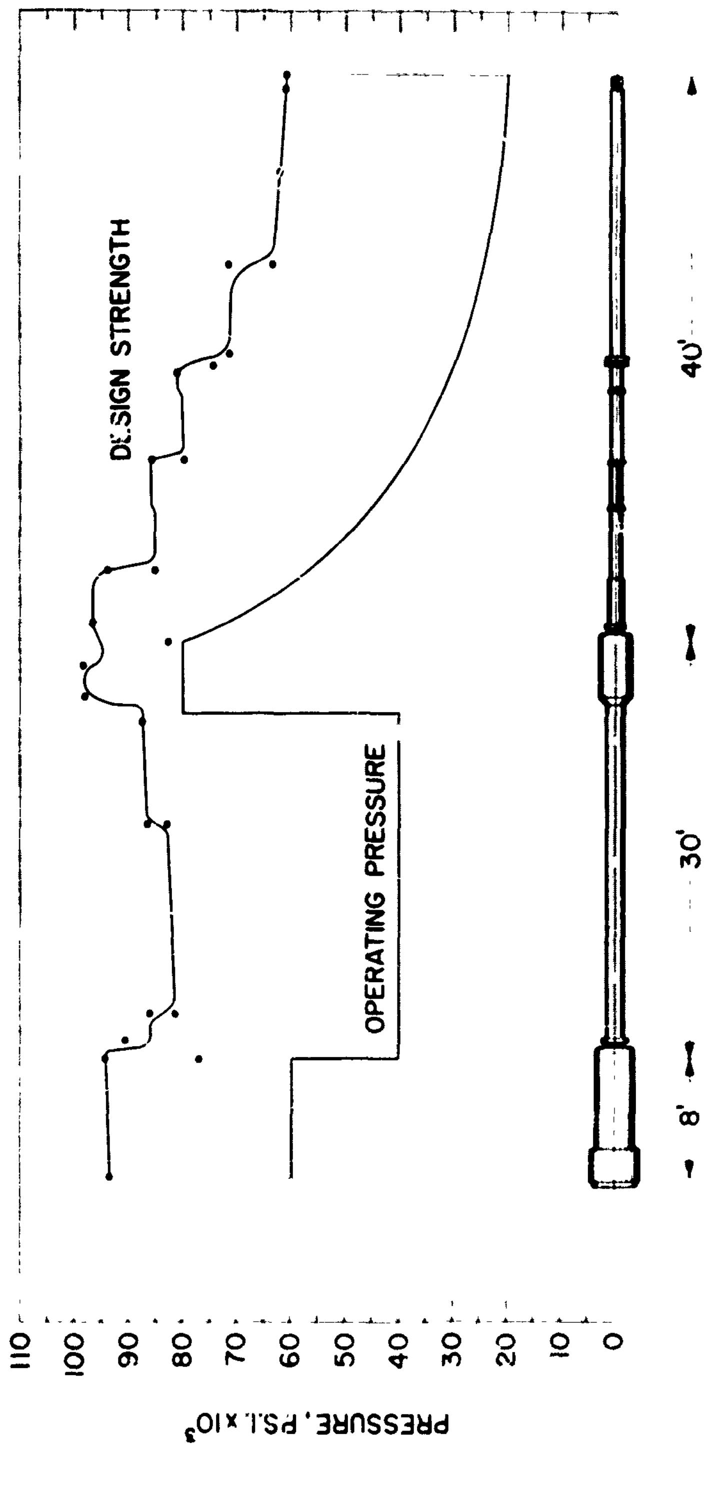

FIG. 3 CALCULATED STRENGTH VALUES
TWO INCH TWO-STAGE LIGHT GAS GUN

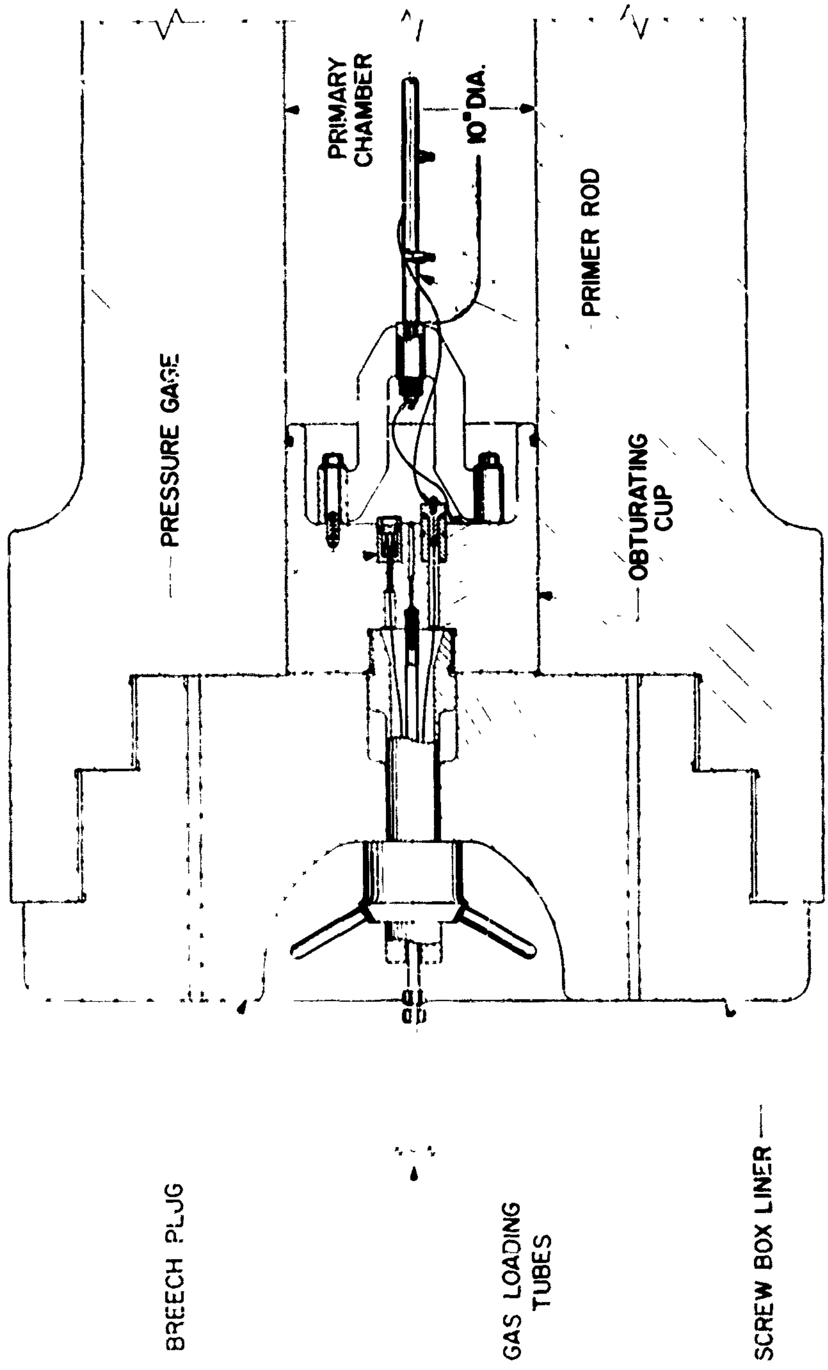

FIG. 4 PRIMARY CHAMBER BREECH ASSEMBLY

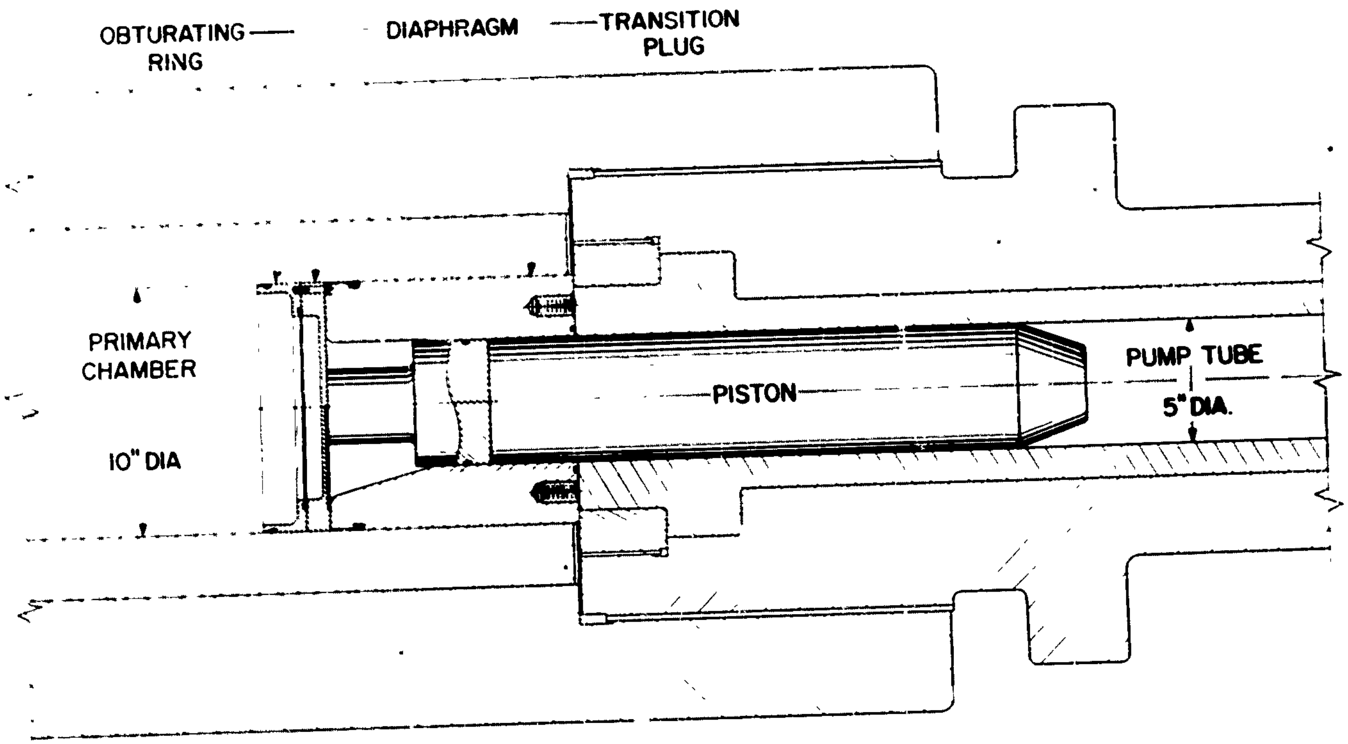

FIG.5 PRIMARY CHAMBER - PUMP TUBE ASSEMBLY

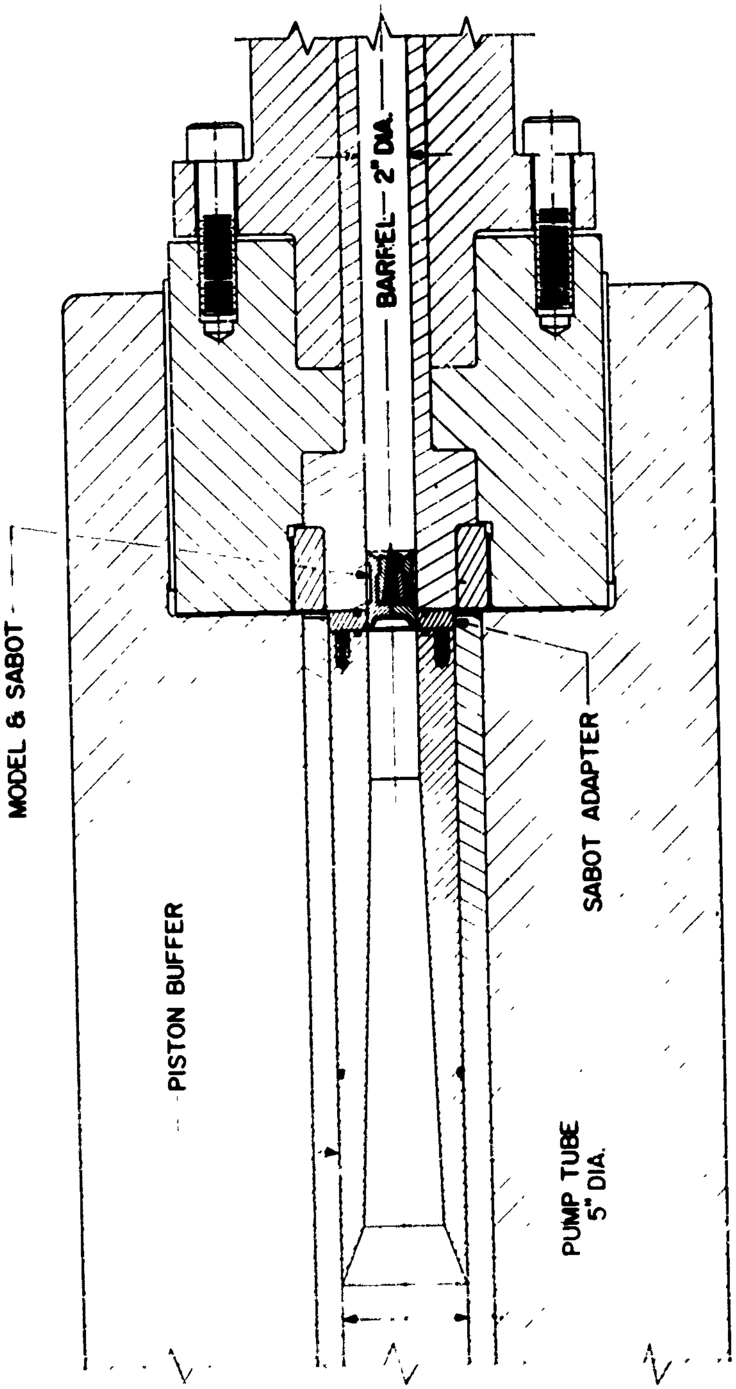

FIG.6 PUMP TUBE - BARREL ASSEMBLY

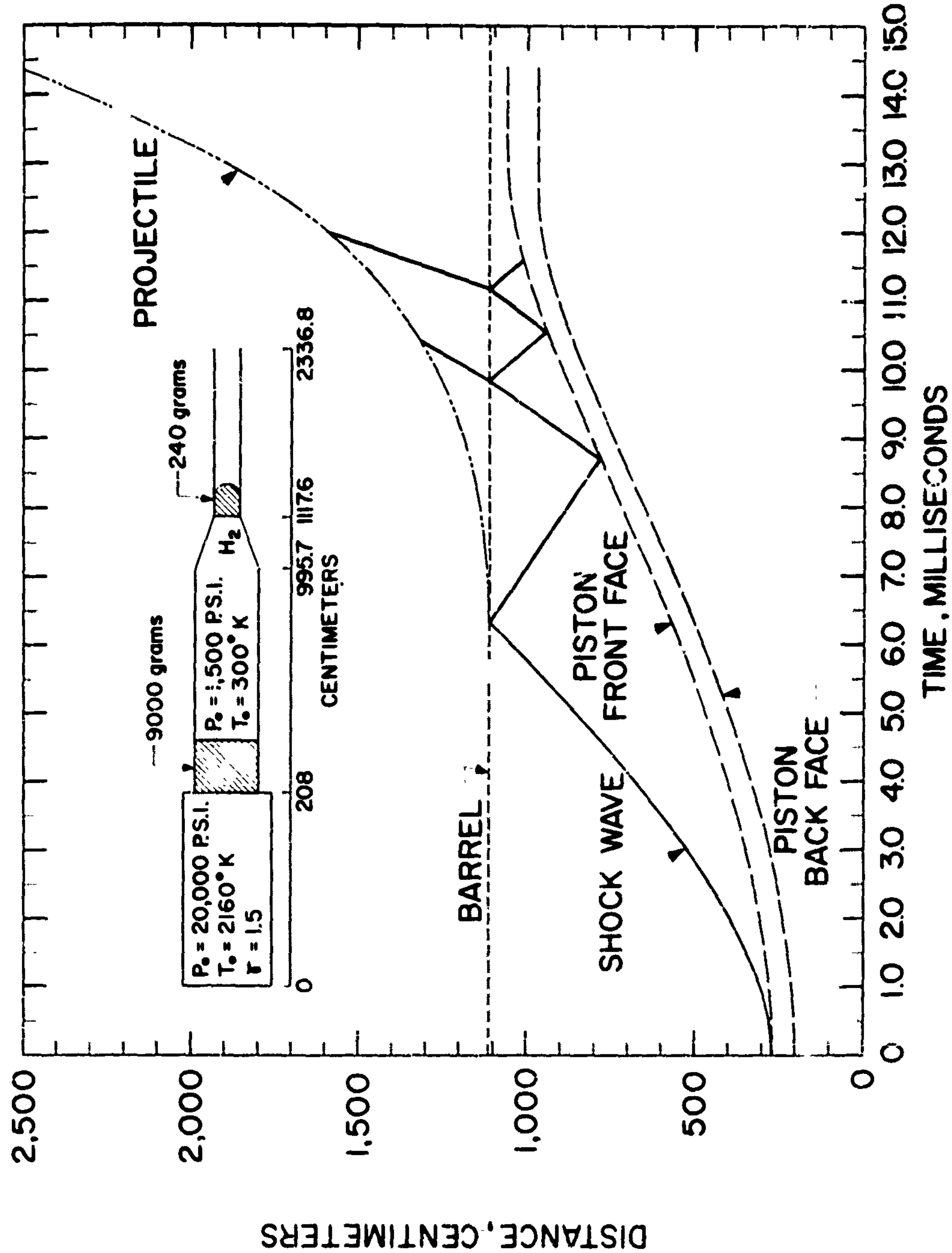

FIG. 7 TWO-STAGE GUN, TIME-DISTANCE PLOT

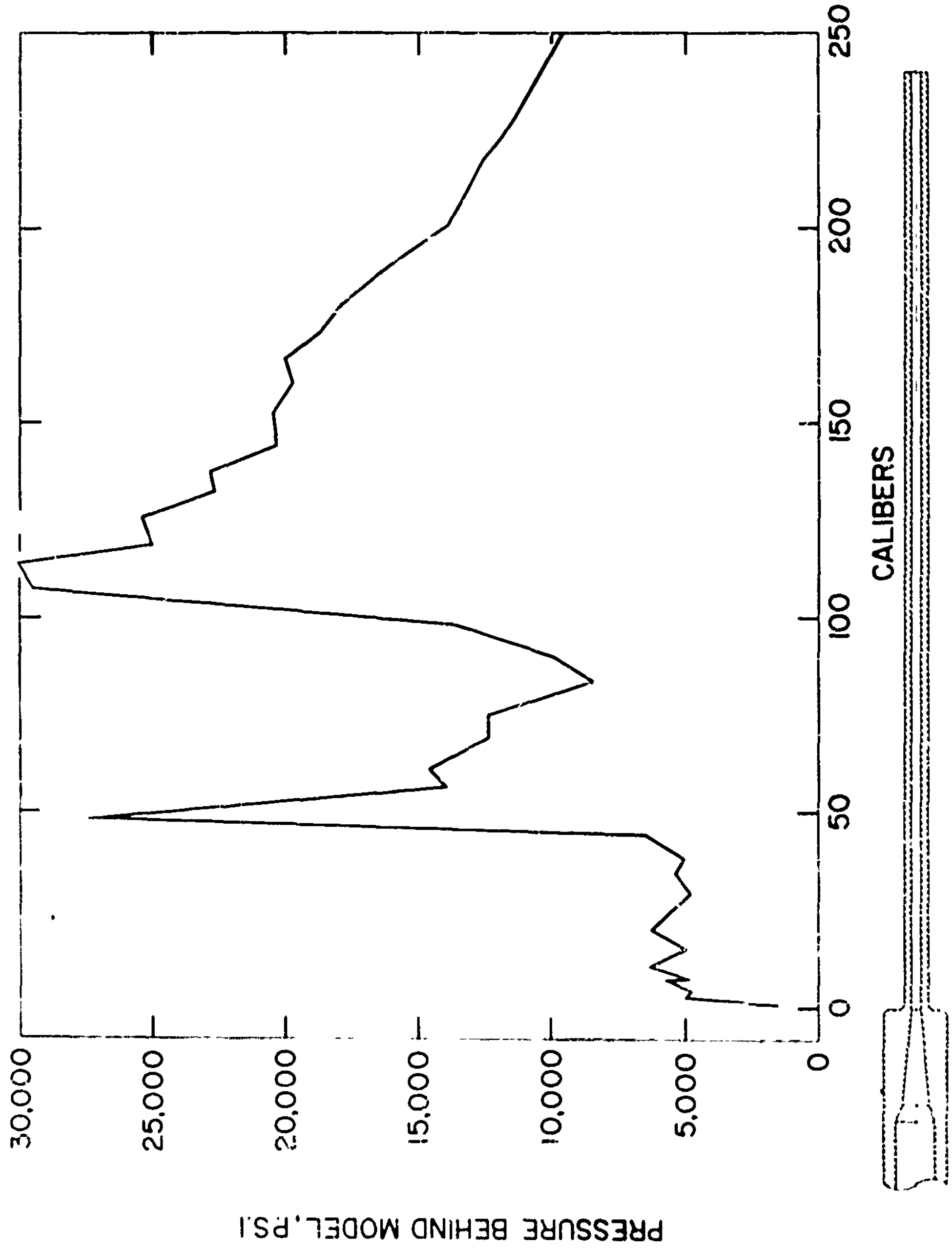

FIG. 8 PRESSURE BEHIND MODEL VS BORE TRAVEL IN CALIBERS

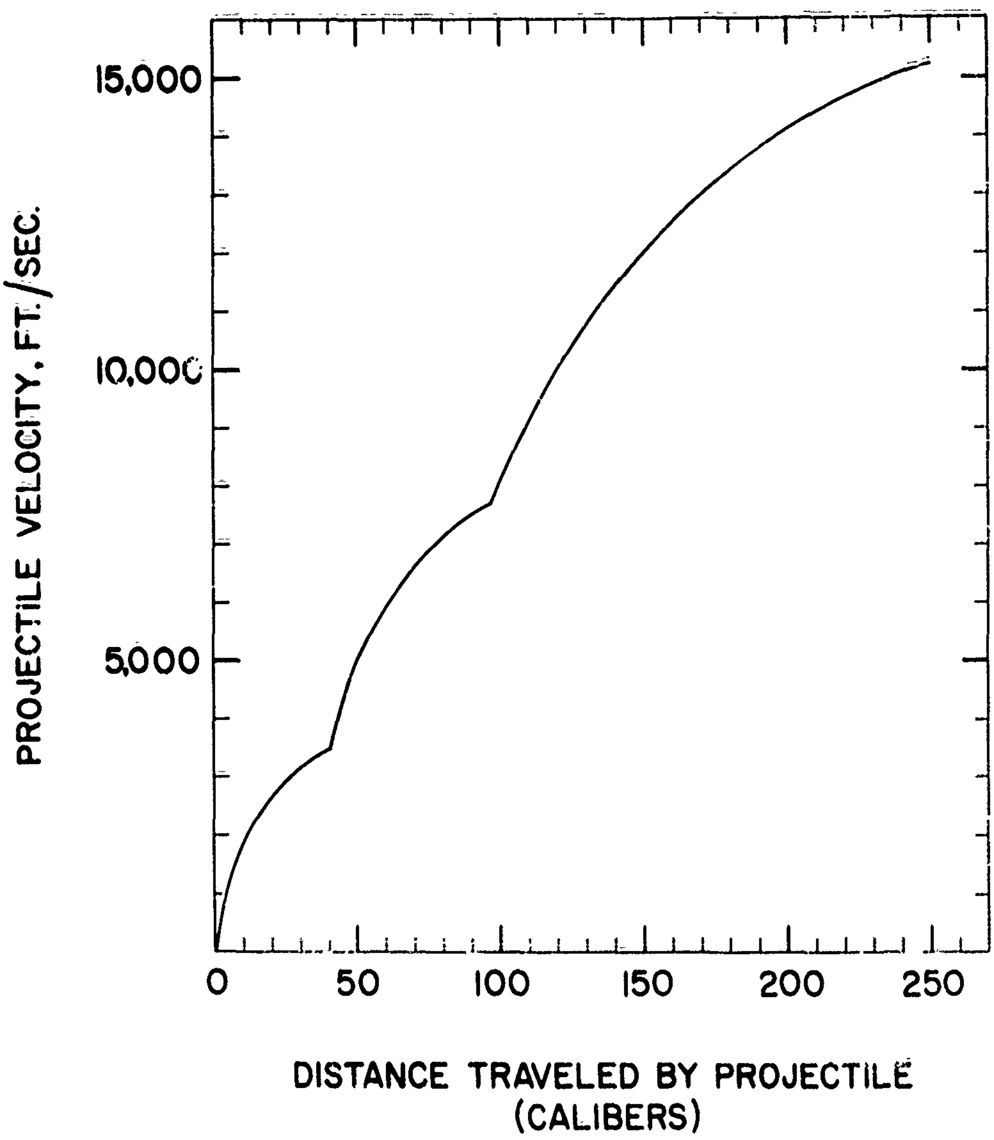

FIG. 9 PROJECTILE VELOCITY VS BORE TRAVEL IN CALIBERS

FIG 10. TYPICAL SHADOWGRAPH OF MODEL IN FLIGHT IN NAVAL ORDNANCE LABORATORY'S 1,000 FOOT HYPERBALLISTICS RANGE NO. 4

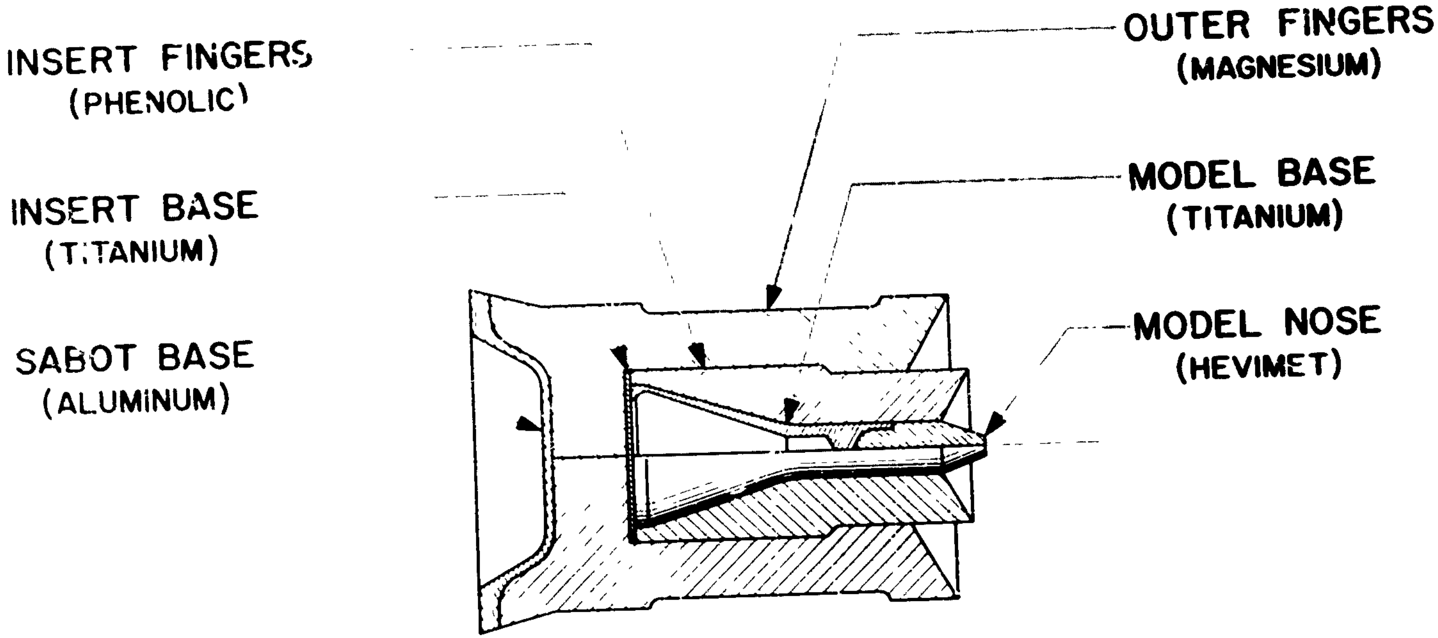

FIG. 11 SABOT AND MODEL

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	[illegible]	CODES		DESCRIPTORS	CODES
[illegible]	NOL Technical Report	NOLTR	SECURITY CLASSIFICATION AND CODE COUNT	Unclassified - 24	U024
REPORT NUMBER	62-12	620112	CIRCULATION LIMITATION		
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SUBJECT ANALYSIS OF REPORT

DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
Two-stage	TWOS	Aerodynamics	AERD		
Gas	GASE	Hypervelocity	HYPV		
Gun (design)	GUNSD	Mach	MACH		
Gun tests	GUNST	10	10X00		
Two	TWOO	12	12X00		
Inch	INCH	14	14X00		
Gun	GUNS	Firings	FIRI		
Ballistic range	BALR	Launchings	LAUC		
Test	TEST	Missile	MISL		
Facilities	FACI	Models	MODL		
Hyperballistic	HYPB	Configuration	CONF		
High velocity	HIGS	Body	BODY		

PRNC-NOL-5070 29 (5-62)

Naval Ordnance Laboratory, White Oak, Md.
(NOLTR report 62-112)
THE DESIGN AND TESTING OF THE NAVAL ORDNANCE LABORATORY'S 2-IN. TWO-STAGE GUN(U), by H.L. Carter and others. 29 June 1962. 4p. tables. (Ballistics Research report 71).

UNCLASSIFIED

A 2-in. two-stage gun has been successful in launching complex models in the Naval Ordnance Laboratory's 1,000-ft. Hyperballistics Range No. 4 at velocities in excess of 15,000 fps. The design of the 2-inch gun and the results of the first 44 shots are reviewed.

Abstract card is unclassified

1. Hypervelocity guns - Design
2. Hypervelocity guns - Interior ballistics
I. Title
II. Carter, H.L.

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